

METHOD FOR THE PRODUCTION OF A PLURALITY OF  
OPTOELECTRONIC SEMICONDUCTOR CHIPS AND OPTOELECTRONIC  
5 SEMICONDUCTOR CHIP

This patent application claims the priority of German  
Patent Application 10335081.0, the disclosure content  
of which is hereby incorporated by reference.

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The invention relates to a method for the production of  
a plurality of optoelectronic semiconductor chips each  
having a plurality of structural elements with  
respectively at least one semiconductor layer. In this  
15 case, semiconductor layers of the structural elements  
are grown by means of selective epitaxy. The invention  
additionally relates to an optoelectronic semiconductor  
chip produced according to this method.

20 Such an optoelectronic semiconductor chip and a  
corresponding method for the production thereof are  
described in DE 199 11 717 A1, for example. Said chip  
has a plurality of radiation coupling-out elements  
comprising e.g. an epitaxially grown semiconductor  
25 layer sequence with an active layer that generates  
electromagnetic radiation. This component thereby has  
improved coupling-out of radiation.

One of the specified methods for the production of the  
30 radiation coupling-out elements comprises selective  
epitaxy. In this case, firstly a continuous mask layer  
is applied, into which windows are subsequently  
introduced by means of photolithography and etching.  
Semiconductor layer sequences are deposited selectively  
35 into the windows and the mask layer is subsequently  
removed again by means of etching.

Such a method has the disadvantage of comprising not only the growth of a mask layer but also the relatively complicated method steps of photolithography and etching, which usually has to be carried out in a  
5 separate installation.

The present invention is based on the object of providing a simpler and more cost-effective method for the production of optoelectronic semiconductor chips of  
10 the type mentioned in the introduction. A further object of the present invention is to provide a semiconductor chip produced according to such a method.

These objects are achieved by means of a production  
15 method having the features of claim 1 and, respectively, by means of an optoelectronic component having the features of claim 18. Claims 2 to 17 relate to advantageous developments of the method.

20 According to the invention, the method for the production of a plurality of optoelectronic semiconductor chips of the type mentioned in the introduction comprises at least the following method steps:

25 provision of a chip composite base having a substrate and a growth surface;

growth of a non-closed mask material layer onto the growth surface in such a way that the mask material layer has a plurality of statistically distributed  
30 windows having varying forms and/or opening areas, a mask material being chosen in such a way that a semiconductor material of the semiconductor layer that is to be grown in a later method step essentially cannot grow on said mask material or can grow in a  
35 substantially worse manner in comparison with the growth surface;

essentially simultaneous growth of semiconductor layers on regions of the growth surface that lie within the windows; and singulation of the chip composite base with applied material to form semiconductor chips.

The production of the mask material layer with window openings can accordingly advantageously be effected by means of a single method step. The growth of the mask material layer is expediently effected in situ in an installation in which semiconductor layers of the component are also grown.

Preferably, the chip composite base has at least one semiconductor layer grown epitaxially onto the substrate. In this case, the growth surface is a surface on that side of the epitaxially grown semiconductor layer which is remote from the substrate.

The method according to the invention is suitable in this case for producing both arbitrary semiconductor layers of the chip composite base and the mask layer and semiconductor layers of the structural elements without restrictions in a single reactor.

In one advantageous embodiment of the method, the chip composite base has a semiconductor layer sequence grown epitaxially onto the substrate, said semiconductor layer sequence comprising an active zone that emits electromagnetic radiation. The growth surface is correspondingly a surface on that side of the semiconductor layer sequence which is remote from the substrate. The semiconductor layers of the structural elements that are subsequently applied to the growth surface form a patterning which, by way of example, fulfills the purpose of improved coupling-out of the electromagnetic radiation generated in the chip

composite base.

As an alternative or in addition, the structural elements respectively have an epitaxially grown  
5 semiconductor layer sequence with an active zone that emits electromagnetic radiation.

Preferred materials for the mask material layer have  $\text{SiO}_2$ ,  $\text{Si}_x\text{N}_y$  or  $\text{Al}_2\text{O}_3$ .

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After the growth of the semiconductor layers of the structural elements, a layer made of electrically conductive contact material that is transmissive to an electromagnetic radiation emitted by the active zone is  
15 preferably applied to said semiconductor layers, so that semiconductor layers of a plurality of structural elements are electrically conductively connected to one another by the contact material. It is thereby possible to form electrical contact structures which absorb a  
20 small proportion of electromagnetic radiation generated in the component.

The average thickness of the mask material layer is preferably less than the cumulated thickness of the  
25 semiconductor layers of a structural element, whereby it is possible to produce structural elements with advantageous forms.

In one embodiment of the method, the mask material  
30 layer is expediently at least partly removed after the growth of the semiconductor layers.

In a further embodiment of the method, after the growth of the semiconductor layer sequences, advantageously as  
35 an alternative or in addition to the removal of mask material, a planarization layer is applied over the growth surface. This may lead to improved coupling-out

of light particularly when a material whose refractive index is lower than that of adjoining semiconductor layers is chosen for said planarization layer.

- 5 The planarization layer preferably has a material having dielectric properties.

The method affords the possibility of producing very differently patterned mask material layers with  
10 respectively differently sized and differently shaped windows in them. By way of example, the growth conditions for the growth of the mask material layer may advantageously be set in such a way that three-dimensional growth is predominant and the mask  
15 material layer is predominantly formed from a plurality of three-dimensionally growing crystallites.

As an alternative, growth conditions for the growth of the mask material layer are advantageously set in such  
20 a way that two-dimensional growth is predominant and the mask material layer is predominantly formed from a plurality of two-dimensionally accreting partial layers.

- 25 In the growth of the mask material layer and the semiconductor layers of the structural elements, provision is likewise advantageously made for varying the growth conditions during growth such that, by way of example, three-dimensional growth is predominant at  
30 the beginning of the growth process and two-dimensional growth is subsequently predominant.

Preferably, the growth conditions for the growth of the mask material layer are set in such a way that most of  
35 the windows are formed with an average propagation of the order of magnitude of micrometers. As an alternative it is possible to produce most of the

windows with an average extent of less than or equal to 1  $\mu\text{m}$ .

5 In this context, propagation is to be understood as the length of a window projected onto a straight line, the straight line running in a principal extending plane of the mask material layer. The average propagation is accordingly the propagation of a window averaged over all directions.

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With the setting of the growth conditions, it is possible in the growth of the mask material layer not just to vary the form or the size of the windows, rather it is also advantageously possible, by way of  
15 example, to set the surface density with which the windows are produced on the growth surface.

In the growth of the semiconductor layers of the structural elements, the growth conditions are  
20 preferably set and alternatively or additionally varied during growth in such a way that the semiconductor layers are formed with a form that is advantageous for the coupling-out of electromagnetic radiation, for example an at least appropriately lenslike form.

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The mask material layer and the semiconductor layers are particularly preferably grown by means of metal organic vapor phase epitaxy (MOVPE).

30 The optoelectronic semiconductor chip is characterized by the fact that it is produced according to the method of the invention or an embodiment thereof.

Further advantages, preferred embodiments and  
35 developments of the method and, respectively, of the optoelectronic semiconductor chip emerge from the

embodiments explained below in conjunction with Figures 1A to 3, in which:

5 Figures 1A to 1D show a schematic plan view of a detail from a growth surface during different stages of an embodiment of the method;

Figure 2 shows a schematic sectional view of a detail from a first embodiment of the optoelectronic component; and  
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Figure 3 shows a schematic sectional view of a detail from a second embodiment of the optoelectronic component.  
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In the embodiments and figures, identical or identically acting constituent parts are respectively provided with the same reference symbols. The constituent parts illustrated and also the size relationships among the constituent parts are not to be regarded as true to scale. Rather, some details of the figures are illustrated with an exaggerated size in order to afford a better understanding.  
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25 Figures 1A to 1D show in chronological succession in each case a detail from a growth surface 3 during the growth of a mask material layer 11 made from a mask material 1. The growth surface 3 may be for example an area of a substrate made from n-GaAs; the mask material 1 is composed e.g. of  $\text{Si}_x\text{N}_y$ .  
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The growth of the mask material 1 begins at isolated points on the growth surface 3 at which crystallites of mask material 1 form. The crystallites of mask material 1 accrete laterally in the further course of events (see Figures 1B to 1D), in which case the growth conditions may be set for example in such a way that  
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two-dimensional growth is predominant, that is to say that the crystallites of mask material 1 grow predominantly in a plane parallel to the growth surface, and only to a lesser degree perpendicular thereto. As an alternative, through corresponding setting of the growth conditions, it is also possible to achieve predominantly three-dimensional growth of the crystallites, that is to say a growth in which the growth rate is of similar magnitude or of an identical order of magnitude in all possible growth directions.

Growth conditions are in this case to be understood as externally settable, controllable or changeable parameters such as e.g. pressure, temperature, material flow and growth duration in the epitaxy reactor. The precise values for such parameters for obtaining a specific growth characteristic can vary greatly and depend for example on the partitioning and the geometrical dimensions of the epitaxy reactor or on the material to be grown.

The production of a non-closed  $\text{Si}_x\text{N}_y$  layer is effected for example in an MOVPE reactor by admitting  $\text{SiH}_4$  and  $\text{NH}_3$  at a suitable reactor temperature, which may typically lie in a range of between 500 and 1100°C. However, the reactor temperature may also lie above or below this range. Such methods are described for instance in Hageman, P.R. et al., phys. stat. sol. (a) 188, No. 2 (2001), 659-662, the content of which is in this respect hereby incorporated by reference. As an alternative, the Si source used may also be tetraethyl-silicon ( $\text{Si}(\text{C}_2\text{H}_5)_4$ ) or a similar Si-containing compound which is suitable for epitaxy.

In the growth stage shown in Figure 1D, the mask material layer 11 has been fully formed. It has a plurality of statistically distributed windows 2 having

varying forms and opening areas. The deposition conditions are chosen for example such that most of the windows have an average extent of the order of magnitude of micrometers. As an alternative, most of  
5 the windows may also have an average extent of less than 1  $\mu\text{m}$ . It is thereby possible to produce more and smaller structural elements and e.g. to achieve improved coupling-out of radiation from the component structures.

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Subsequently, for example semiconductor layer sequences 8 are deposited selectively on regions of the growth surface 3 that lie within said windows 2 (see Figure 2 or 3). Said semiconductor layer sequences may be based  
15 for instance on phosphide compound semiconductors and preferably have materials  $\text{In}_n\text{Ga}_m\text{Al}_{1-n-m}\text{P}$ , where  $0 \leq n \leq 1$ ,  $0 \leq m \leq 1$  and  $n+m \leq 1$ . In this case, these materials may have one or more dopants and additional constituents which essentially do not change the  
20 physical properties of the material.

A semiconductor layer sequence 8 forms a structural element 12. In the sense of the invention, it is also possible in this case for semiconductor layers of a  
25 plurality of structural elements to overlap or for a plurality of structural elements to have at least one common semiconductor layer. This is the case for example if semiconductor layer sequences 8 grow laterally over the mask material layer to an extent  
30 such that semiconductor layers of adjacent structural elements 12 partly or wholly accrete. In such cases a boundary between two adjacent structural elements runs along a line along which semiconductor material situated on the mask material layer has a minimum  
35 thickness.

In Figure 2, the semiconductor layer sequence 8 forming the structural element 12 has an active zone that emits electromagnetic radiation when current is applied. However, a structural element 12 may also have no  
5 active zone and e.g. be formed from only one semiconductor layer having a lenslike form.

The active zone may have a conventional pn junction, for example for a light emitting diode. Such structures  
10 are known to the person skilled in the art and are therefore not explained in any greater detail at this juncture.

By virtue of the fact that the windows have opening  
15 areas of different magnitudes, different material compositions result for the layers of the semiconductor layer sequences 8 that are deposited therein. In the case of structures emitting electromagnetic radiation, different emission spectra consequently result, so that  
20 with radiation-emitting components of this type it is possible overall to achieve a broader emission spectrum than with conventional components.

Figure 2 shows a schematic sectional view of a detail  
25 from an optoelectronic component produced by the method. The chip composite base 5 comprises a substrate 4 and a semiconductor layer or semiconductor layer sequence 6 which is grown epitaxially on said substrate and whose side remote from the substrate 4 forms the  
30 growth surface 3. A mask material layer 11 is grown on the growth surface 3 and, in the component detail shown, has a window into which a semiconductor layer sequence 8 is selectively deposited.

35 The maximum thickness of the mask material layer 11 may be e.g. only a few nm and is less than the height of the semiconductor layer sequence 8. As a result,

semiconductor layers of the semiconductor layer sequence 8, above a height that is greater than the thickness of the mask material layer 11 surrounding them, are also partly grown over the mask material layer 11 by lateral growth.

The growth conditions for the growth of the semiconductor layer sequence 8 are e.g. chosen or varied during growth in such a way that the semiconductor layer sequence 8 is formed with a lenslike form. As an alternative, said form may also be like a truncated cone or polyhedral.

In this context, the term "growth conditions" is to be understood in a manner similar to the growth of mask material 1 explained above. In this case, how precisely the setting of specific values for parameters such as pressure, temperature, material flow and growth duration affects the growth of semiconductor materials depends not only on the type of semiconductor material to be grown and the type of epitaxy installation but also greatly on the type of mask material 1.

In the embodiment illustrated in Figure 2, the semiconductor layer grown last covers all the remaining semiconductor layers of the semiconductor layer sequence 8. This makes it possible to apply a layer made from electrically conductive contact material 7 for example flat over the entire growth surface 3 or on the semiconductor layer sequence 8 and the mask material 1 without different semiconductor layers of the semiconductor layer sequence 8 being electrically short-circuited. Suitable contact material 7 is for example indium tin oxide (ITO) or else a metal layer a few atomic layers thick, for example made from platinum, which due to its small thickness is transmissive to a radiation emitted by the active zone

of the semiconductor layer sequence 8.

A contact material with ITO may additionally have a thin metal layer of this type which is deposited before  
5 the ITO. It is thereby possible to improve the electrical conductivity of the contact between contact material 7 and semiconductor layer sequence 8.

In order that an electrically conductive contact forms  
10 between the contact material 7 and the semiconductor layer sequence 8, after the application of the contact material 7 the component generally has to be subjected to heat treatment at a suitable temperature for a sufficiently long time. These measures are known to the  
15 person skilled in the art and are therefore not explained in any greater detail.

A bonding pad via which the semiconductor layer sequence can be contact-connected from one side e.g. by  
20 means of a bonding wire (not shown) may be applied to the contact material 7 before or after the heat treatment.

If the substrate 4 is provided with a contact material  
25 and electrically conductively connected on the rear side, that is to say on the side remote from the growth surface, then a voltage can be applied via the bonding pad and the rear side contact directly to the still united components and their functionality can be tested  
30 (direct probing).

In the case of the component of the detail shown in Figure 2, the semiconductor layer sequence 6 arranged on the substrate 4 may alternatively or additionally  
35 also have an active zone that emits electromagnetic radiation. When a voltage is applied to the component, the current is restricted through the mask material

layer 11 to a region of the windows 2, so that a light generating region is essentially restricted to a part of the active zone of the semiconductor layer sequence 6 which lies below a window 2.

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Figure 3 shows the detail from a second embodiment of the component. In contrast to the embodiment explained with reference to Figure 2, the production method in this example comprises, after the application of the semiconductor layer sequence 8, removal of the mask material layer 11, which may be effected by selective etching.

15 A planarization layer 10 is subsequently applied to the growth surface 3 and the semiconductor layer sequence 8, which planarization layer may be composed e.g. of a dielectric whose refractive index is lower than that of materials of the semiconductor layer sequence 8.

20 In order that electrically conductive contact can be made with the semiconductor layer sequence 8, the planarization layer 10 is then at least partly thinned or removed, so that the outermost layer of the semiconductor layer sequence 8 is uncovered.

25 Subsequently, analogously to the exemplary embodiment explained with reference to Figure 2, electrically conductive contact material 7 is applied thereto and heat treatment is effected.

30 Subsequently, the chip composite base 5 with the applied material can be singulated to form a plurality of optoelectronic semiconductor chips. Each of these semiconductor chips comprises a plurality of structural elements 12 arranged alongside one another.

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The scope of protection of the invention is not restricted by the description of the invention on the

basis of the embodiments. By way of example, the windows in the mask material layer can be made so small that quasi one-dimensional semiconductor component structures are grown in them. The invention encompasses  
5 any new feature and also any combination of features, which in particular comprises any combination of features in the claims even if this combination is not explicitly specified in the patent claims.